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NOISE REDUCTION IN A TURBULENT JET BY THE METHOD OF REPEATED AIR INJECTION

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NOISE REDUCTION IN A TURBULENT JET BY THE METHOD OF REPEATED AIR INJECTION

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ABSTRACT. If air is injected normal to the jet axis at the boundary of the jet, optimal exit velocity profiles can be obtained which lower acoustic power emission. Expressions are derived for the flow parameters in a turbulent axisymmetrical gas jet. Application of this technique results in a noise level reduction of approximately 21 dB.

In the operation of modern passenger aircraft with jet engines the noise /28*
of the turbulent jet is the critical feature in many cases, primarily on take-off. Reduction of it is especially necessary in the creation of supersonic transport aircraft and may be achieved by the provision of an optimal velocity gradient in the jet.

The exit velocity profile in a free turbulent jet has a substantial influence on the noise emitted [1]. The acoustic power emitted by the jet is determined in the literature [2, 3] by the equation

$$W = k \int_{\Omega} \frac{\rho^2 l^7}{4\pi\rho_0 c_0^5} \cdot \left(\frac{\partial u}{\partial r}\right)^8 d\Omega \qquad (1)$$

where k is constant;

ρ, ρ_0 is the relative density of the gas in the jet and in the surrounding medium;

C_0 is the velocity in the sound in the surrounding medium;

l is the scale of turbulence;

u is the local longitudinal velocity of the stream;

Ω is the volume of emission.

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*Numbers in the-margin indicate pagination in the foreign text.

Let us consider an axisymmetric jet emitted into a stationary medium. We shall assume that $l = cx$ (where c is constant), $\rho = \rho_0$ = constant. We write expression (1) in the cylindrical coordinate system:

$$W = k_1 \int_x \int_r x^7 \left(\frac{\partial u}{\partial r}\right)^8 dr dx. \tag{2}$$

We determine the optimal velocity profile in the jet which provides the minimal acoustic emission. The Ostrogradskiy equation for the given extremum of the problem has the form [4]

$$\frac{\partial}{\partial r}\left[\frac{\partial F}{\partial p}\right] = 0, \tag{3}$$

$$F = x^7\left(\frac{\partial u}{\partial r}\right)^8 r;\ p = \frac{\partial u}{\partial r}.$$

The solution of equation (3) within the region of the turbulent stream with boundary conditions corresponding to the jet and to the source ($u = 0$ on the upper boundary of the jet and $u = u_0$ along the axis of the jet):

$$\frac{u}{u_0} = 1 - a\eta^{\frac{6}{7}} \tag{4}$$

where $n = \frac{r}{x}$, $a = \eta_1^{-\frac{6}{7}}$, $\eta_1 = \frac{r}{x}$ -- are the jet boundary equations.

From the equation of continuity /29

$$\frac{\partial (ru)}{\partial x} + \frac{\partial (rv)}{\partial r} = 0 \tag{5}$$

we find the distribution of the transverse velocity v in the given region of the stream, with the assumption that the longitudinal velocity along the axis of the jet changes according to the rule $u_0(x) = \frac{\eta}{x}$ and with the condition $v = 0$ on the axis of the jet

$$\frac{v}{u_0} = \frac{1}{2}\eta(1-1.3a\eta^{\frac{6}{7}}). \tag{6}$$

The distribution of pressure in this case satisfies the equation of motion [5]

$$u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial r} = \frac{1}{\rho}\frac{\partial \tau}{\partial x} - \frac{1}{\rho}\frac{\partial p}{\partial r}, \tag{7}$$

where

$$\tau = \rho l^2 \left|\frac{\partial u}{\partial r}\right| \frac{\partial u}{\partial r}.$$

The differential pressure on the axis of tne jet relative to the surrounding medium is obtained with the aid of expression (7), amounting to $0.003\rho \frac{u_0^2}{2}$. The pressure in the jet may thus be considered to be constant.

It is known [6] that the stream to the main part of the jet can lead to a stream from the local source of turbulence. Therefore the equations (4) and (6) are the conditions of minimal acoustic emission by the main part of the jet.

Solving equation (3) for the region of the initial portion of the jet with the boundary conditions

$$u = 0 \text{ when } r = r_0 + \eta_2 x,$$

$$u = u_0 \text{ when } r = r_0 - \eta_3 x,$$

where η_2 and η_3 determine the boundaries of the mixing region, we find the optimal velocity profile

$$\frac{u}{u_0} = \frac{(r_0+\eta_2 x)^{\frac{6}{7}} - r^{\frac{6}{7}}}{(r_0+\eta_2 x)^{\frac{6}{7}} - (r_0-\eta_3 x)^{\frac{6}{7}}}. \tag{8}$$

The transverse velocity in the mixing region of the jet with the condition $v = 0$ on the boundary of the potential core is

$$\frac{v}{u_0} = \frac{3}{7} b_1 r\left[1-\left(\frac{r_0}{r} - \eta_3\frac{r}{3r}\right)^2\right] - \frac{3}{10} b_2 r^{\frac{13}{7}}\left[1-\left(\frac{r_0}{r} - \eta_3\frac{x}{3r}\right)^{\frac{20}{7}}\right], \tag{9}$$

where

$$b_1 = \frac{r_0(\eta_2+\eta_3)(r_0+\eta_2 x)^{-\frac{1}{7}}(r_0-\eta_3 x)^{-\frac{1}{7}}}{\left[(r_0+\eta_2 x)^{\frac{6}{7}}-(r_0-\eta_3 x)^{\frac{6}{7}}\right]^2};$$

$$b_2 = \frac{\eta_2(r_0+\eta_2 x)^{-\frac{1}{7}}+\eta_3(r_0-\eta_3 x)^{-\frac{1}{7}}}{\left[(r_0+\eta_2 x)^{\frac{6}{7}}-(r_0-\eta_3 x)^{\frac{6}{7}}\right]^2}.$$

In a comparison of the acoustic power emitted by the initial portion of the jet and calculated according to formula (2) for the normal and optimal (8) velocity distributions we discover a reduction of the noise level by ~21 dB. /30

For the case of wakes the optimal longitudinal velocity profile can be obtained in the initial phase

$$\frac{u}{u_0} = \frac{(r_0+\eta_2 x)^{\frac{6}{7}}-m(r_0-\eta_3 x)^{\frac{6}{7}}-(1-m)r^{\frac{6}{7}}}{(r_0+\eta_2 x)^{\frac{6}{7}}-(r_0-\eta_3 x)^{\frac{6}{7}}}.$$

Here $m = \frac{u_1}{u_0}$, where u_1 is the wake velocity.

The functions for the transverse velocities may be described by equation (9) with the values

$$b_1 = \frac{(1-m)r_0(\eta_2+\eta_3)(r_0+\eta_2 x)^{-\frac{1}{7}}(r_0-\eta_3 x)^{-\frac{1}{7}}}{\left[(r_0+\eta_2 x)^{\frac{6}{7}}-(r_0-\eta_3 x)^{\frac{6}{7}}\right]^2}$$

$$b_2 = \frac{(1-m)\left[\eta_2(r_0+\eta_2 x)^{\frac{1}{7}}+\eta_3(r_0-\eta_3 x)^{\frac{1}{7}}\right]}{\left[(r_0+\eta_2 x)^{\frac{6}{7}}-(r_0-\eta_3 x)^{\frac{6}{7}}\right]^2}$$

The results of these investigations can be utilized to calculate the reduction of the jet noise. In order to realize the optimal velocity profile in the jet it is necessary to inject air into the jet in accordance with expressions (6) and (9). In conformity with formula (6), in the injection of air normal to the jet axis along the surface $\eta_1 = \frac{r}{x}$ it is necessary to realize

$$\frac{v}{u_0(x)} = -0.15\eta_1.$$

Similar expressions can be obtained for the initial phase of the jet.

By means of the method given for the determination of optimal profiles it is possible to infer the case of supercritical drops in the nozzle.

Thus the possibility exists for theoretical evaluation of the effectiveness of noise-reducing nozzles from the supply of secondary air, proposed, for example, for the supersonic passenger plane, the Concorde [7].

REFERENCES

1. Powell, A., "The Influence of the Exit Velocity Profile on the Noise of a Jet," *Aeronaut. Quarterly*, No. 4, pp. 341-360, 1954.
2. Ribnet, H. S., "On the Strength Distribution of Noise Sources Along a Jet," *J. Acoust. Soc. America*, Vol. 30, No. 9, p. 876, 1958.
3. Munin, A. G., *Svyaz' aerodinamicheskikh i akusticheskikh parametrov dozvukovoy gazovoy strui. SB. "Promyshlennaya aerodinamika"* [Relationship of Aerodynamic and Acoustic Parameters of a Subsonic Gas Flow. Series "Industrial Aerodynamics,"] *Oborongiz Press*, Moscow, No. 23, 1962.
4. El'sgol'ts, L. E., *Differentsial'nye uravneniya i variatsionnoe ischislenie* [Differential Equations and the Calculus of Variations], Nauka Press, Moscow, 1965.
5. Bay Shi-I., *Teoriya struy* [Theory of Flow], Fizmatgiz Press, Moscow, 1960.
6. Abramovich, G. N., *Teoriya turbulentnykh struy* [Theory of Turbulent Flows], Fizmatgiz Press, Moscow, 1960.
7. Richter, G., *Recherches de la SNECMA sur la reduction de bruit des jets* [Research by SNECMA in the Reduction of Jet Noise], International Conference on the Reduction of Noise and Disturbance Caused by Civil Aircraft, London, Nov. 1966, Paper INC/C1/P20.

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